Global environmental changes

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We are the inhabitants of a precious place, planet Earth. As we try to understand what the makes our planet tick, we are confronted with an incredible array of forces and effects that all interact. We need to understand each force and effect, but more importantly we need to see the connectivity among them. The multiplicity of interactions, however, makes it very difficult to sort out the single drivers. We always talk about atmosphere, ocean, and land, but people are now becoming an equal part of the dynamic that causes the Earth to behave in the fashion that it does. In fact, population dynamics and urbanization form an incredible array of drivers that cause the processes to take place.

The time and spatial scales that we have to deal with are incredible, whether it is atmospheric composition that changes over centuries and global scales, or tornadoes that operate, say, in the Oklahoma basin for a few tens of minutes. We care most about the regional or very local scale. If you are living in the Imperial Valley of California, the projected patterns of the next 100 years don't look terribly attractive for adequate water for agriculture and food products that have flourished during the 20th century. These are issues that are real threats to our security as a nation, and frankly the threats to peace around the world.

Fortunately there is a magnificent convergence occurring as the new millennium begins, as new theoretical modeling and observational techniques are coming into use. Massive increases in computer capacity will enable global climate models to look at how the planet works. About a 100-terraflop machine will be necessary to produce global climate model with a 10-kilometer-resolution, and several nations are making heavy investments in the next generation supercomputers.

We also have been making progress on the issue of differences in our climate models. If you ask the climate community using several different models to run projections out into the next century, the divergence of their predictions has narrowed greatly (Figure 12-1). We are homing in; the band of uncertainty among our climate models is getting smaller and smaller. Being able to use the models in retrospect to explain what actually happened in the past is also getting a lot better.

Our capacity to look at global-scale processes will be magnificently transformed through the Earth-observing satellite capability that NASA, Japan, and Europe are developing. The 24 measurements planned in the current incarnation of the Earth Observing Satellite will dramatically change our capacity to understand processes in the ocean, for example.

We have learned interdisciplinary approaches to problem solving from projects undertaken in the International Geophysical Year. This was the first massive attempt to attack issues like understanding the biomes in the northern hemisphere; to bring Third World scientists to the table as we never have before; to assess where we go into the Amazon, not as the United States only or as a few countries, but as a consortium of probably 10–15 nations, looking at a series of land-atmosphere interaction processes. So

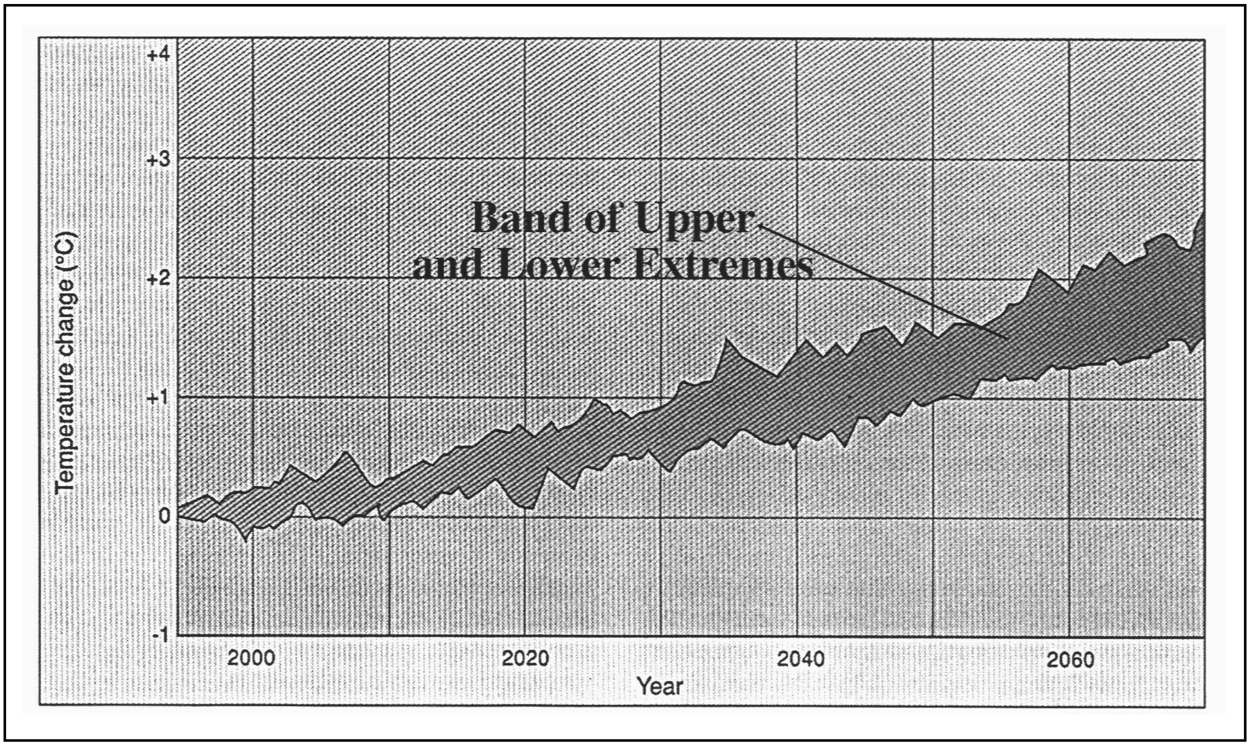

Figure 12-1. The range in predicted change in the global mean surface temperature (C°) for years 2000-2080.

our capacity to get at these problems is clearly improved dramatically over the past, particularly in the past decade.

With this said, I would like to outline some of the global-scale evidence of enduring change, change that challenges science and will challenge us, I suspect, for decades to come. Inevitably we will have to seriously address the connections between man's activities and these changes, but we should also understand and even predict nature's own quirks and changes. These environmental effects will impact our security in both the narrow and broad senses.

Improving predictions: The El Niño example

In the last decade we have gotten a handle on prediction for certain parts of the planet. A massive array of buoys in the central Pacific measures the sea-surface temperature and a series of other parameters that allow us to do some projections about El Niño timing and severity. Several centers around the world and in the United States have done a stunning job in developing and demonstrating this capability.

These predictions are already finding their way into practical use—particularly in the northeast part of Brazil, a region that had traditionally been destitute because of the impact made every 3-7 years by a massive El Niño they could not predict. Today, that region is overcoming its drought sensitivity to El Niño. In 1987, which was a big El Niño year, there was no action taken to mitigate its impact. In 1992, drought resistant seed was used, and there was on the average not only no negative El Niño effect, but even a slight positive effect on grain production. So investments in scientific research have had a beneficial effect and have mitigated some difficult environmental factors.

On the other hand, El Niño has an uncontrollable effect on weather patterns across the United States from tornadoes in Oklahoma to mini-monsoons in the Caribbean and, of course, floods and droughts on our Pacific coast. The effect on our insurance industry and our economy has been devastating. Since 1980, 20 events (floods, hurricanes, earthquakes) have each caused in excess of a billion dollars in damage; the cost alone from hurricane Andrew in 1992 was $16 billion. We still have a great deal to learn before we can control or mitigate these effects.

Natural and anthropogenic change

The planet wasn't always quite the way it is now—and that becomes a part of the argument: what is normal and does that change? Massive variability has occurred on interglacial time scales: Chicago, Boston, and Cincinnati were all under ice; Greenland was 16 degrees centigrade colder on the average; the tropics were 2–5 degrees cooler; sea level was 100 to 110 meters lower than it is today; mountain snow lines were a kilometer lower in the tropics and in the temperate zone; CO_2 levels were 70% of pre–Industrial Revolution levels. Paleo-data allows us to track changes that were natural certainly up into the mid part of the last 1000 years. Then came the Industrial Revolution.

We cannot continue our linear thinking about the planet— thinking that goes, "Things just change." Our planet doesn't necessarily make easily flowing changes. For example, in the North Atlantic, glaciers melted about 11,000 years ago, creating much less-dense cold surface water, stopping the formation of cold deep-ocean currents, and dropping the temperature in Europe by probably on the order of 6–7 degrees centigrade. This abrupt change is evidence that the planet is metastable; it pops into different states. It popped four degrees in ten years during the glacier melt, according to sediment records.

The planet does respond rapidly. Two weeks after Pinatubo erupted sulfur dioxide wrapped the planet in a belt. The mixing and convective processes of the planet are pretty rapid. This had a cooling effect, produced by all those particles. The sun reflects off of them and doesn't get to the Earth's surface. Pinatubo had a massive effect and caused a measurable cooling. If you look at the temperature record ten years from now, you will see the Pinatubo effect. In fact you can see the leveling off for three or four years of the rising global temperature because of Pinatubo.

Carbon dioxide is sufficiently well mixed that we don't need 5000 measuring stations around the Earth to understand what is happening with it. A few stations adequately cover the trends. Human behavior in the economic world can be detected in the CO_2 change; it is very small, but it is easy to see. Look at the oil crisis of 1973; you can actually see it in the global CO_2 record.

The remainder of this discussion argues that things are changing on a global scale. Whether these are naturally occurring phenomena, anthropogenic, or both, we need to understand them better. How significant are the changes and what are the key drivers? We don't want to put our energy, money, and time on things that are less important. But once we know the answers to these questions, we as citizens of nations of the world are going to have to face them and change the way in which this planet is evolving.

Greenhouse gas accumulation. CO_2, carbon fluorocarbons (CFCs), and methane have been going up at rates approaching a percent a year. CFC increases, which were going up at 5% per year globally, are starting to level off. Methane is going up at 1%. If you put your money in the bank at 1%, you don't do very well, but if you put greenhouse gases in the atmosphere and compound it over decades, the effect is dramatic. CO2 growth over the Industrial Revolution is on the order of 25–30%

To control CFCs, nations of the world did respond. In the mid-1980s scientists started saying that the projections about CO_2 effects were starting to be seen. Then we had the summer of 1988, one of the hottest summers in Washington, D.C. Senator Gore and many others started holding hearings and there was a lot of hype; we ended up with a convention on climate that was signed in Rio.

President Bush had only one White House conference and it was on global warming. President Clinton has had probably upwards of ten conferences dealing with climate-related issues. The next major international summit will be in Kyoto in November, 1997.

North America, Western Europe, and the former Soviet Union started generating considerable CO_2 during the 20th century. China, Brazil, and India have now entered the picture. Indonesia, with the fourth largest population of the world, has not yet begun to generate CO_2 measurable on the global scale. These are the comers, the countries that aspire to the lifestyle to which we are accustomed. They are going to invest in energy, in ways that are not unlike what we have done.

Ozone decrease and UV radiation increase. The Southern Hemisphere ozone maps are familiar. But the Northern Hemisphere is now also experiencing ozone depletion over Russia, the United States, and Greenland (Figure 12-2). The fundamental processes that drive this effect are undoubtedly the same here as over Antarctica, but the dynamics of the Northern Hemisphere are different. There is no northern polar vortex to contain the ozone hole. In fact, we now know that depletion reaches down well into our latitudes during certain times of the year.

Northern stratospheric ozone is down 4–5% and UV-ray radiation is going up at the rate of 4–9% per decade. There is controversy, but the UV numbers are increasing. This is not a healthful development. Fortunately, we do have evidence suggesting that CFC controls will cause this to level off in the decades ahead.

Glacier retreat. There is really good satellite data that shows the reduction in glacial area around the planet. The higher altitudes are even more dramatically affected, but on average glaciers are retreating, consistent with a warming climate.

A couple of years ago in Antarctica, an iceberg calved off the peninsula near Palmer Station, one of the stations that the National Science Foundation supports. This region has warmed on the average 2.5-3 degrees centigrade since roughly the mid to late 1940s, roughly a 2.5^{o}C growth in temperature over 50 years. Some observers will argue, quite persuasively, that some of this calving is driven by the local warming trend.

Precipitation pattern change. We predict a 20% increase in precipitation in the northeast United States and a 10-20% drop in California (Figure 12-3). It appears that we are going to have many more floods in the Mississippi watershed.

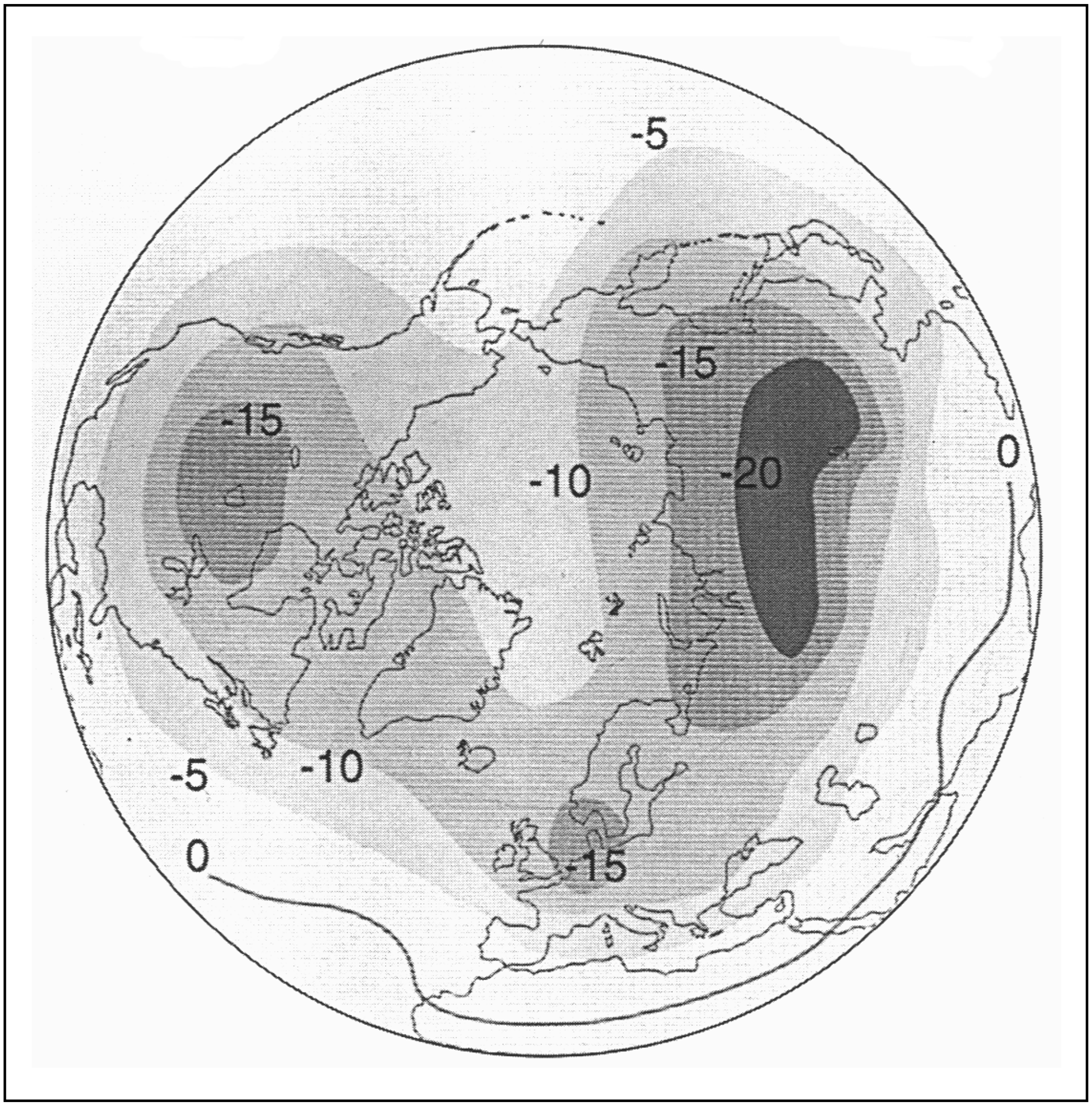

Figure 12-2. Ozone depletion in the northern hemisphere.

Sea level rise. Sea level is on the upward trend as measured in Japan; Honolulu; Sydney, Australia; Bombay, India; San Francisco; and France (Figure 12-4).

Vegetation decrease. Brazilian Amazonia is experiencing major changes in land use. Maybe this is the right thing to do, but at least we now have the satellite data to see what is happening. Human-induced land use degradation, overgrazing, and deforestation, are common in Asia, Africa, and South America (Figure 12-5). In the short time of human history a 20% reduction in vegetated land has occurred. We have changed the pattern in which we use our bioresources, not on a local scale, but on a global scale. The idea of a global threat is a suitable paradigm in this case.

Disease mobility. There is increasing evidence that there is connectivity between climate change and other global environmental phenomena and human health. As the

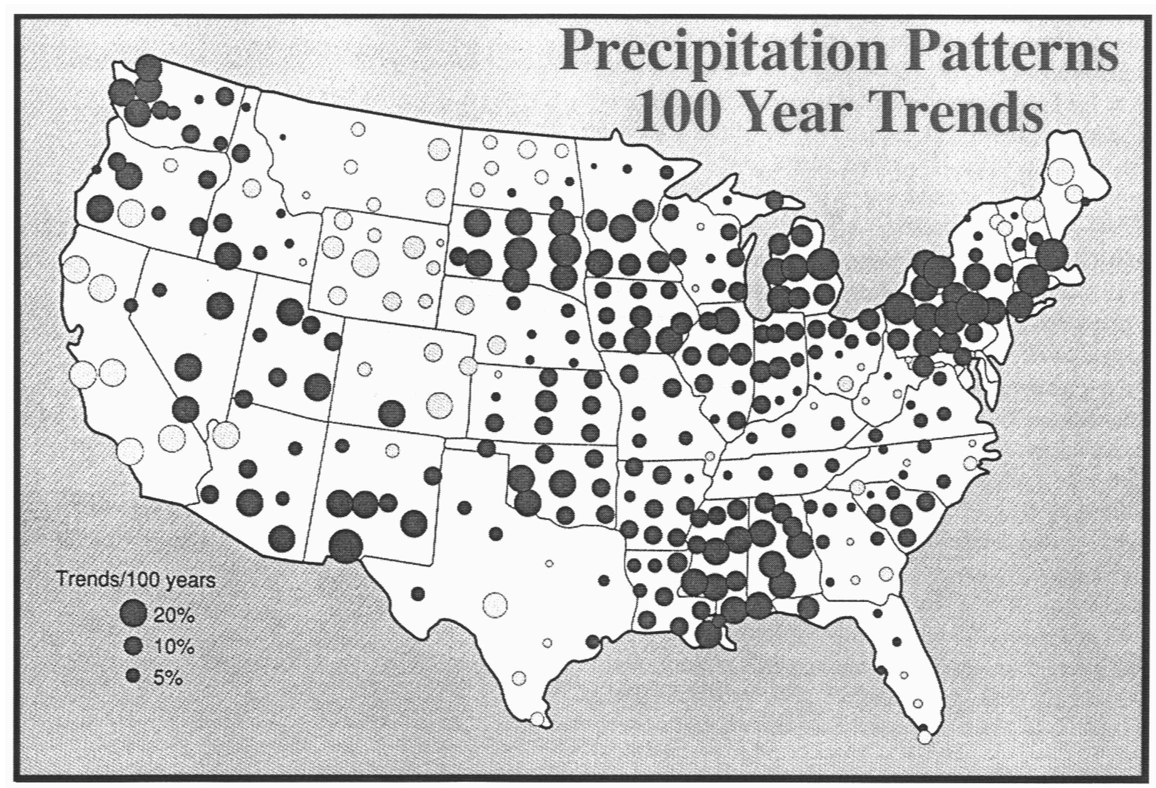

Figure 12-3. 100-year trends in precipitation patterns.

temperature rises to a certain level, disease vectors increase and start moving; they are very temperature sensitive. Diseases are appearing in the Northern Hemisphere that weren't there before.

Research agenda

Some issues that underlie environmental threats to our national security are pervasive and important across the world. From the perspective of the National Science Foundation, which tends to focus on basic research, and of the other agencies who have responsibility of developing research agenda and making investments in global change science, the discussion and development of a focused national R&D agenda is very important.

I can tell you that those of us who convert agenda into programs, like U.S. global change research program, or the Mission to Plant Earth at NASA, or the geosciences and other disciplines at NSF and our fellow agencies, derive great help from these discussions. We need to focus on the research priorities for this complex array of environmental security issues.

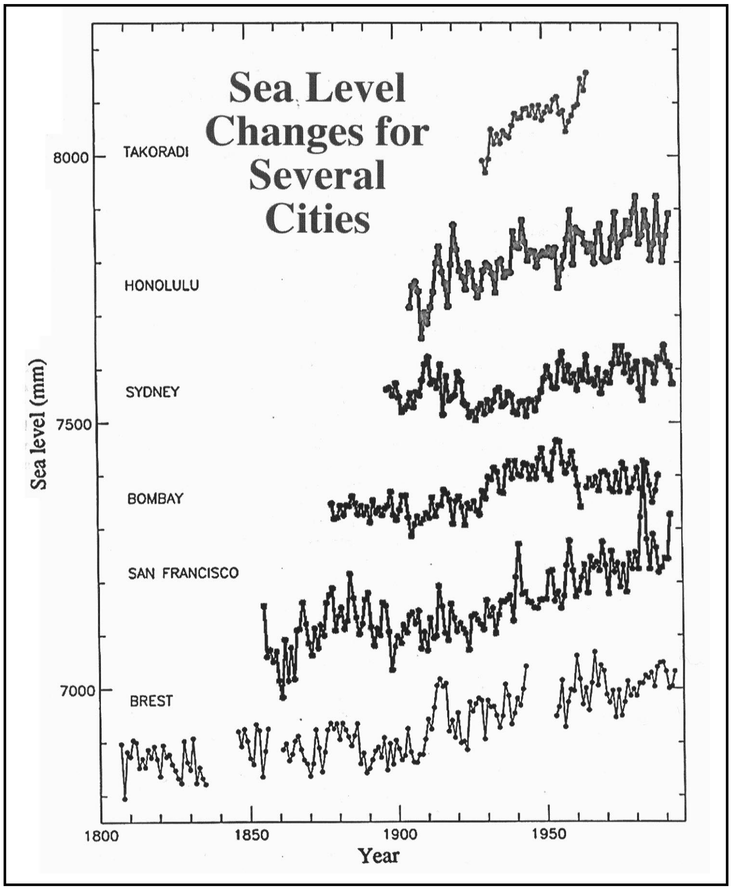

Figure 12-4. Changes in sea level around the world.

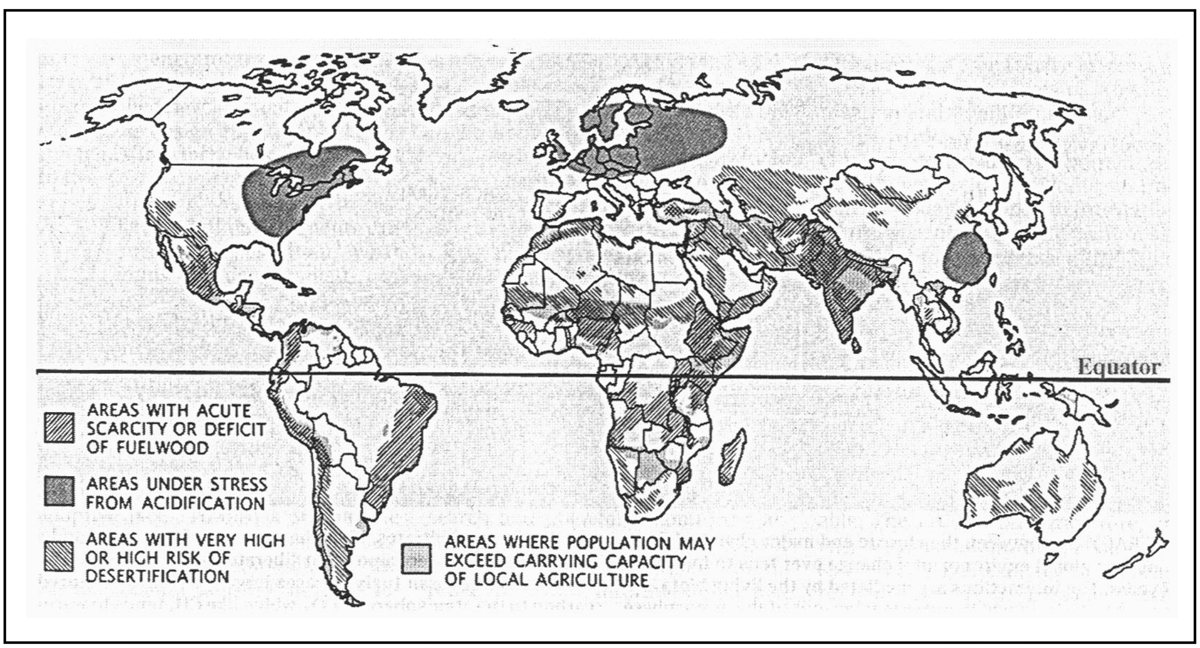

Figure 12-5. Worldwide areas of environmental stress.